Lagrangian Tracer Transport and Dispersion in Shallow Tidal Inlets & River Mouths

R. T. Guza & Falk Feddersen
Scripps Institution of Oceanography
La Jolla, CA 92093-0209
phone: (858) 534-0585 fax: (858) 534-0300 email: rguza@ucsd.edu, falk@coast.ucsd.edu

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LONG-TERM GOALS

Long-term objectives are developing and field testing numerical models of shallow water breaking waves and wave-driven processes including mixing, currents, and transport and dispersion of tracers. Calibrated models will provide improved prediction of the fate of tracers (e.g. pollution, fine sediment, chemicals) in very shallow water.

OBJECTIVES

Objectives during the past year included continued analysis of existing data sets, and extending our existing field capability in preparation for participation in the tidal inlet/river mouth DRI

APPROACH

Wave breaking occurs most of the time on most ocean beaches. Even the most sophisticated numerical models must parameterize the highly turbulent dynamics of wave breaking, and the ensuing cascade of momentum and energy to both larger and smaller scales of motion. Our general approach is to use field observations to test and calibrate the numerical models used to simulate wave-driven beach processes.

The development of new field technique and the acquisition of extensive data sets are key program elements. All aspects of the work, from pre-experiment planning to publication of results, are collaborative with students and post docs.

WORK COMPLETED

- Omand et al. (2009) and Clark et al. (2009), concerning the measurement of chlorophyll and rhodamine WT dye concentrations in the surfzone, have been published.
- Spydell et al (2009), relating drifter dispersion observed during HB06 to sheared alongshore currents in the surfzone, has been published.
- Clark et al. (2010), an analysis of dye dispersion observations during HB06, is in press.
- Omand et al. (2010), describing the evolution of a nearshore red tide during HB06, is in revision.

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- Gorrell et al., (2010), comparing observations and model predictions of waves during the ONR/NSF supported Nearshore Canyon Experiment (NCEX, 2003) experiment, has been submitted.

- The IB09 (Imperial Beach CA) field experiment (Sept-Oct 2009) was completed, and analysis is underway.

- New drifters and mooring hardware have been acquired for use in the Tidal Inlet/River mouth DRI.

RESULTS

Recent and ongoing observations combine arrays of fixed instruments (e.g. current meters, pressure sensors, and fluorometers mounted on frames or moorings) with mobile platforms (e.g. jetskis, small boats). Additionally, Lagrangian observations of transport and mixing are acquired with water-following drifters and fluorescent dye, proxies for pollutants, chemicals from ordnance, and other tracers of interest.

Dye Tracer: Fixed (frame mounted) and mobile (jet ski mounted, Figure 1) methods for in situ measurement of surfzone fluorescent Rhodamine WT dye in turbid and bubbly surfzone waters were developed (Clark et al, 2009). The system can also sample chlorophyl A (Omand et al, 2009). Dye sampling jetski and fixed fluorometers were first deployed at Huntington Beach, as part of the HB06 field experiment. SIO graduate PhD student David Clark is using these observations to characterize surfzone mixing (figure 1). With increasing downstream distance from the source, the alongshore-oriented dye plume widens, and peak concentrations decrease (figure 2). The rate the plume widens (dashed lines in Figure 3), is an estimate of the surfzone diffusivity. Although the observational data base is very limited, potential parameterizations of diffusivity (as a function of wave and current conditions) are emerging (figure 4).

Our most recent field observations, at Imperial Beach in Fall 2009 sampled dye plumes as long as 3km (figure 5 and figure 6 (top)). The jetski samples only at the sea surface, and it is assumed dye is well-mixed vertically in the surfzone. A small boat was used to sample dye concentrations over the vertical, seawards of the surfzone (figure 6, bottom). Analysis of IB09 dye observations form the core of the thesis of PhD student Kai Hally-Rosendahl.

Drifters: Water-following drifters provide an additional method for estimating surfzone transport and mixing. Drifters, deployed on 5 days during HB06 (Figure 7), produce results qualitatively similar to those obtained with dye. For example, the dominant mean transport is by the alongshore drift. Cross-shore mixing is largely confined to the surf zone; with little dye and few drifters leaving the surf zone. In both cases, tracers (dye or drifters) spread rapidly across the surf zone (~50m width, but further cross-shore spreading is weak. Aspects of drifter separation statistics suggest that 2D turbulence with a wide range of eddy scales is causing the surf-zone dispersion. However, the time dependence of the relative dispersion and the diffusivity’s scale dependence differ from 2D inertial-subrange scalings. Thus, the 2D surf-zone eddy field responsible for dispersion is not a classical 2D inertial subrange (an energy cascade). The source of this vorticity-dominated eddy field with length scales 5–50 m vorticity is not understood. Shear waves likely would input vorticity at longer length scales O(100 m) which, for flat-bottom 2D turbulence, would cascade energy to larger length scales—too large to explain the

observed 5–50-m scale dependent diffusivities. The source of vorticity (eddies) with scales less than about 50 m may be alongshore gradients in breaking-wave height associated with finite crest length. Longer drifter trajectories are being studied in the IB09 field experiment (Figure 8).

IMPACT/APPLICATIONS

Tracer evolution and transport in the nearshore is important to Navy/Marine objectives including chemically detecting mines, avoiding contact with dangerous substances, and predicting where optical clarity will be effected by fine sediments and silt. A goal is to develop a portable (between sites) model suite that, given bathymetry and incident wave conditions, predicts (perhaps qualitatively) tracer transport and dilution.

RELATED PROJECTS

Huntington Beach (HB06) and Imperial Beach (IB09) observations and analysis were funded by ONR, NSF, and Sea Grant. The upcoming DRI observations at New River, NC will build on this framework.

PUBLICATIONS (2009- present) acknowledging ONR support

Omand, M., F. Feddersen, D.B. Clark, P.J.S. Franks, J. J. Leichter , and R.T. Guza, The Influence of Bubbles and Sand on Chlorophyll-a Fluorescence Measurements in the Surfzone, Limnol. Oceanogr.: Methods7, 2009, 354–362 , 2009. [published, refereed].

Clark, D.B., F, Feddersen, and R.T. Guza , Measuring Fluorescent Dye in the Bubbly and Sediment Laden Surfzone; Water, Soil, and Air Pollution, DOI 10.1007/s11270-009-0030-z 2009. [published, refereed].

Spydell, M., F. Feddersen, and R.T. Guza, Observations of drifter dispersion in the surfzone: The effect of sheared alongshore currents. J. Geophys. Res. Oceans, 114, C07028, doi:10.1029/2009JC005328., 2009. [published, refereed].

Clark, D.B., F, Feddersen, and R.T. Guza, Cross-shore Surfzone Tracer Dispersion in an Alongshore Current, , J. Geophys. Res. Oceans. [in press, refereed]

Omand, Melissa M., J Leichter, P Franks, R. T. Guza, A. J. Lucas, and Falk Feddersen, Physical and biological processes underlying the sudden appearance of a red-tide surface patch in the nearshore, Limnology and Oceanography. [in revision, refereed]

SWAN Predictions of Waves Observed in Shallow Water Onshore of Complex Bathymetry. Gorrell L.,B. Raubenheimer, Steve Elgar, and R.T. Guza, Coastal Eng. [submitted, refereed]

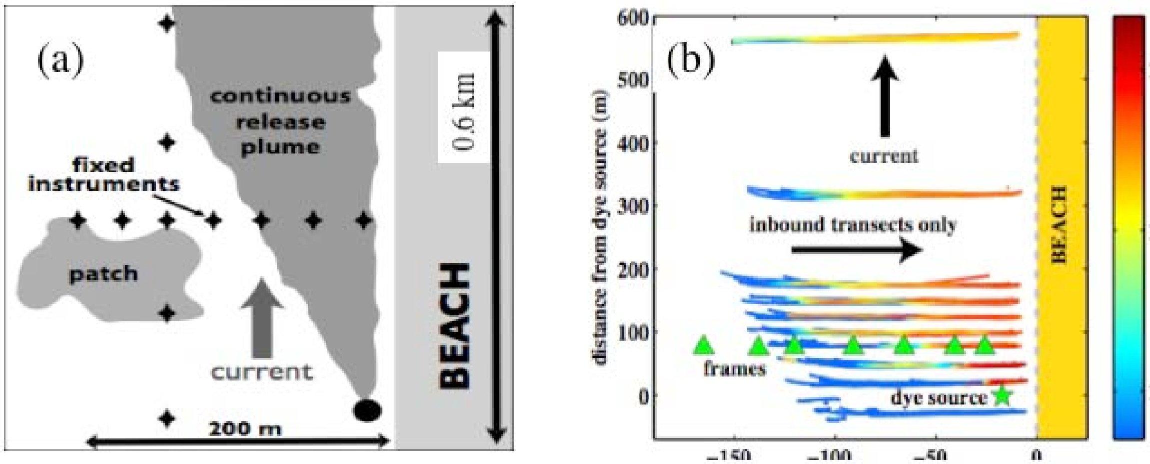

Figure 1: (a) Schematic of HB06 dye plume mixing experiment. Fixed instruments (current meters and pressure sensors) measured waves and currents on cross- and alongshore transects. Dye was measured at (usually) 4 locations with fixed fluorometers, and with a jetski. Dye was released as a single patch, and continuously forming a plume. (b) ski-sampled dye concentrations across a dye plume are indicated by colors (scale to the right). During a 4-hr plume release on 11 Oct 2006, the mean alongshore current near the shoreline was 20 cm/s, and the breaker height was 50 cm. About 10 passes were made along each transect.

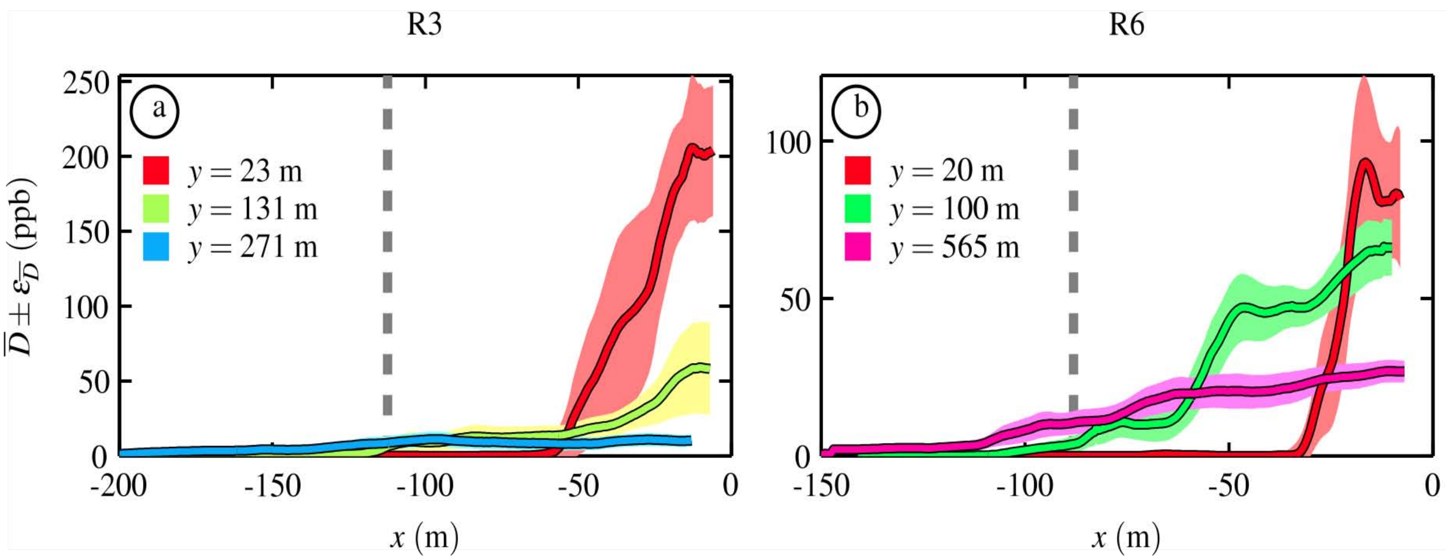

Figure 2: Mean dye profile curves D(x; yj) with lighter regions indicating range of D(x; yj) incuded in the average, for dye releases (a) R3 and (b) R6 at three alongshore distances y from the dye source (see legend). The dashed gray line indicates the seaward edge of the surfzone. Vertical scales differ.

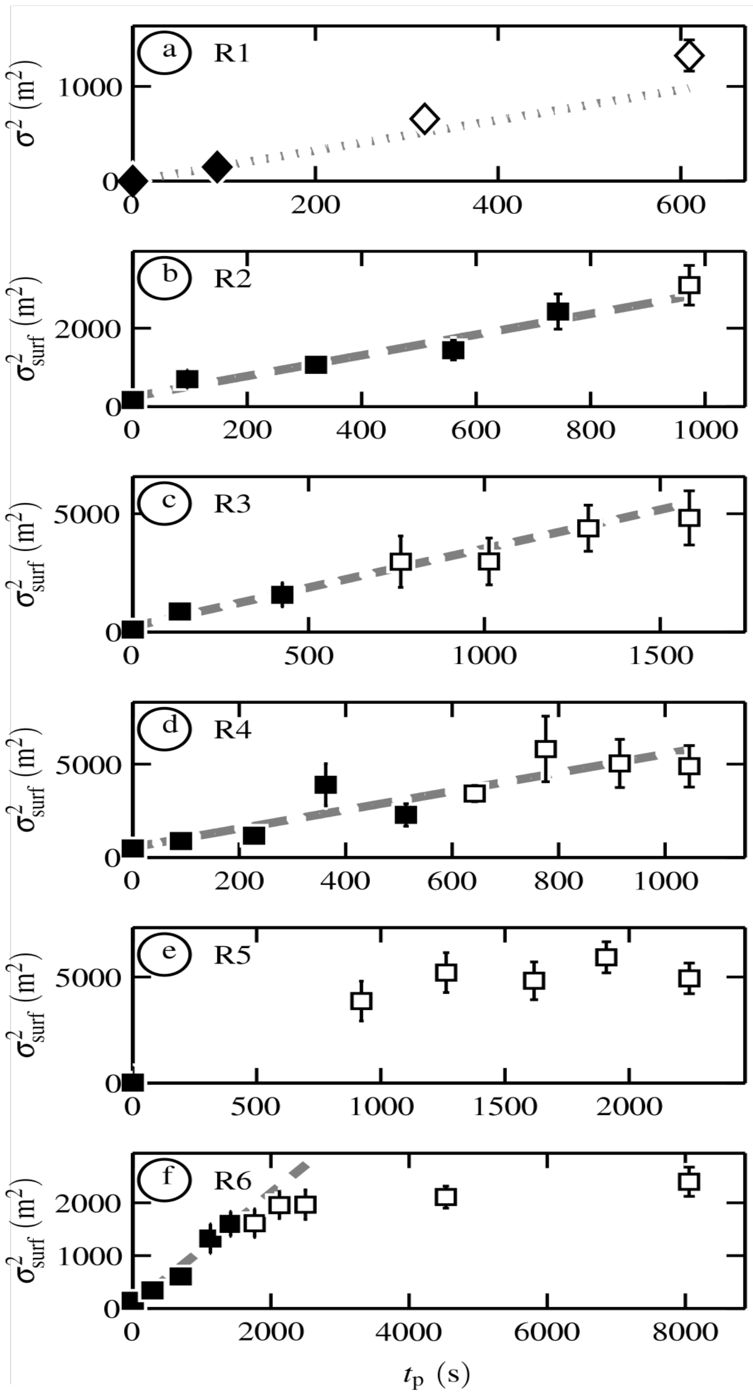

Figure 3: Squared plume width versus advection time t_p for releases (a) R1, (b) R2, (c) R3, (d) R4, (e) R5 and (f) R6. Black symbols indicate points used to determine the line slope, equal to the diffusivity. between t_p = 0 and the farthest downstream transect with dye largely confined within the surfzone.

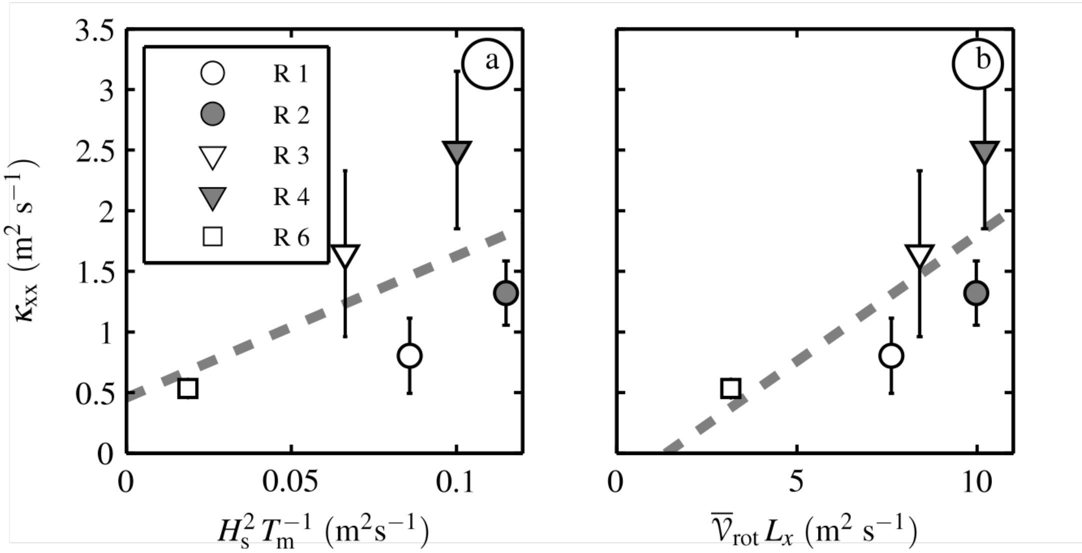

Figure 4: Estimated surfzone cross-shore diffusivity versus (a) wave breaking parameter (b) surfzone vorticity parameter.

Figure 5: Aerial photograph during the IB09 plume experiment with South swell. Dye injected continuously near the shoreline was advected northward (toward the image top) by the breaking-wave driven alongshore current. A fixed array of instruments (downcoast of the Imperial Beach Pier, upper left) spanned from the shoreline to about 5m depth. The jetski sampling pattern was similar to Huntington Beach (figure 1) but spanned several km of dye plume (figure 6).

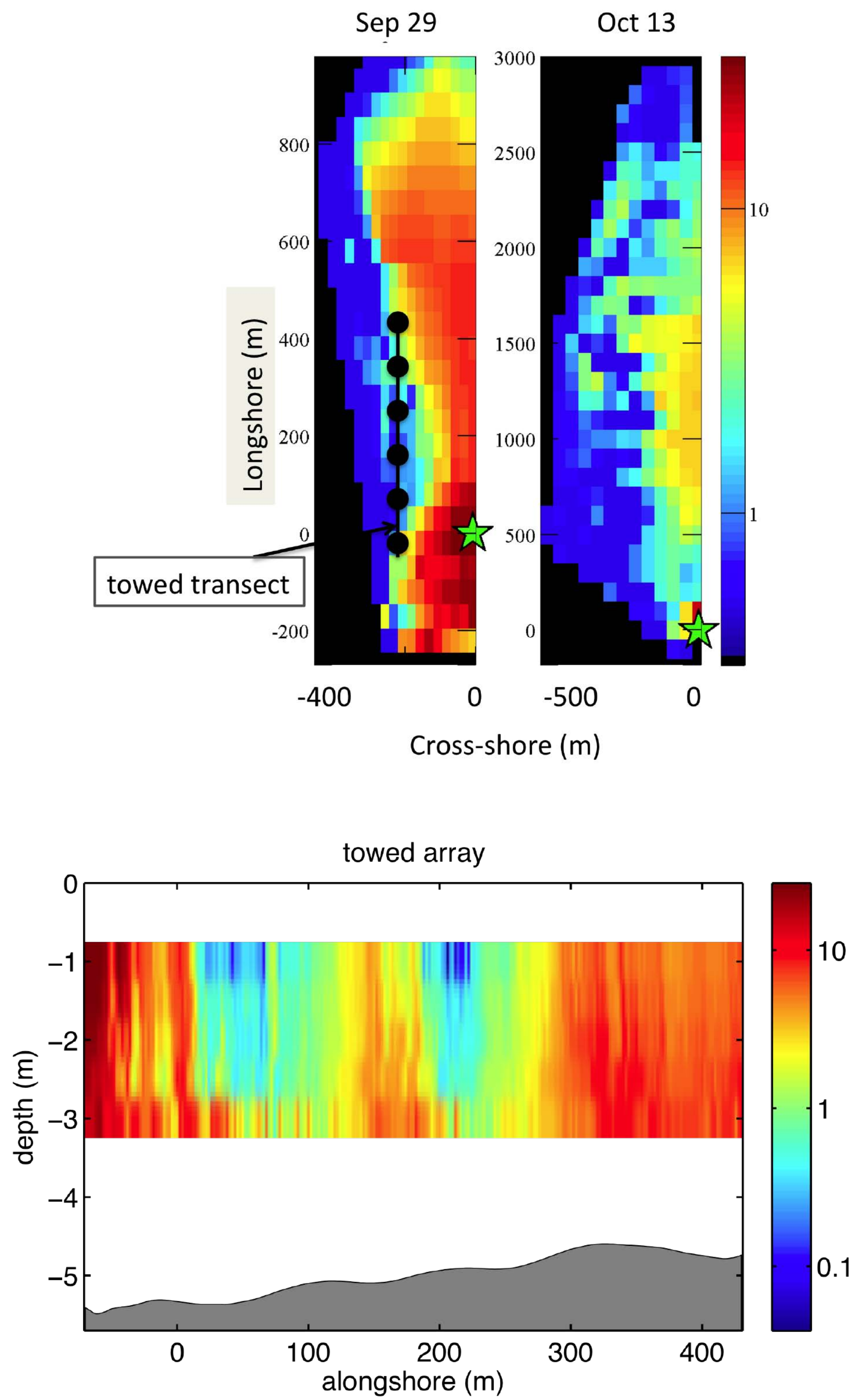

Figure 6: IB09 (upper) plan view of dye concetration maps on 2 days. On Oct 13 (right), the plume is detectable 2.5km downstream from the dye source (green star). The black line in Spe 29 (left) shows the alongshore trasnsect of (lower) dye concentration versus depth and alongshore location

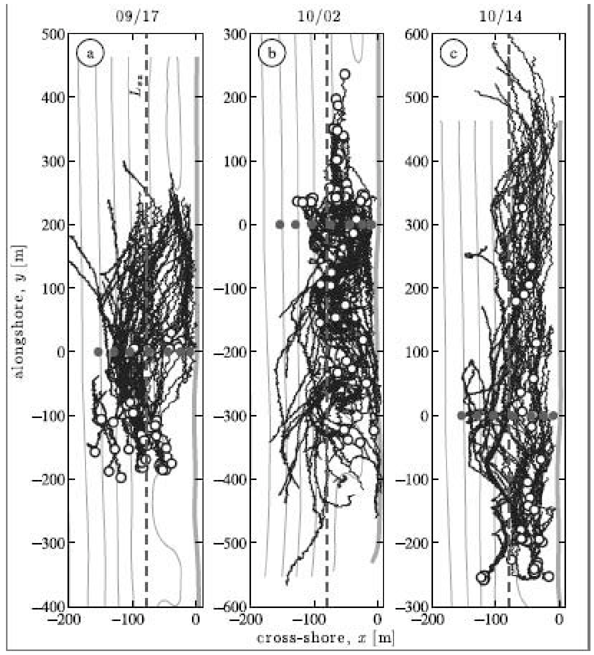

Figure 7: Drifter trajectories (black curves) for 3 days during HB06. Open circles are drifter release locations. Individual drifters moved as much as 600m alongshore, but less than 100m offshore.

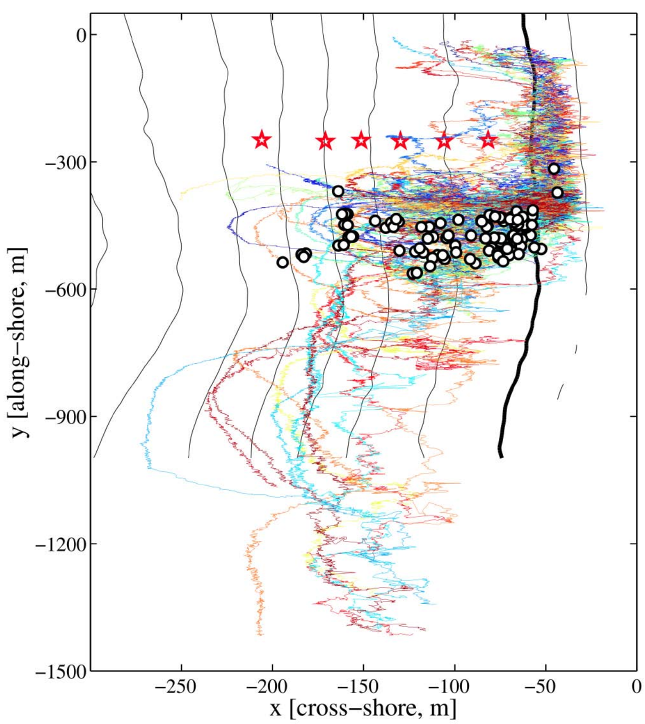

Figure 8: Drifter trajectories (colored curves) during one day at IB09. Drifters moved both up- and down-coast from the release locations (open circles)